

# Wind Turbine Reliability and Service Improvements

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# An increased need for reliability...

- Global wind electricity-generating capacity increased by 24 percent in 2005 to 59.1 gigawatts. This represents a twelve-fold increase from a decade ago, when world wind-generating capacity stood at less than 5 GW. \*
- With wind becoming a key part of the electrical mix in Denmark (20% with 3.1 GW), Spain (8% with 10 GW), and Germany (6% with 18.4 GW) wind turbine reliability is having a bigger effect on overall electrical grid system performance and reliability. \*
- With this rapid growth rate (29% over the last ten years) has come an invaluable data set that helps identify the most pressing reliability and O&M issues that face this rapidly growing industry.
- Tracked by groups like Windstats, RISOE and others, a good data base has emerged that is helping designers and operators get the most out of their machines.

\* Source: Worldwatch, GWEC and the Earth Policy Institute

## As new designs are deployed...

- The configuration, technology and size of wind turbines has been changing rapidly over the last ten years.
- What was once largely stall-regulated, constant speed machines in the 50-500 kW range in the 1980s has evolved in the late 90s to modern variable pitch, variable speed turbines with power electronics in the 750 kW to 2+ MW range.
- With these new turbine architectures have come added capabilities and improved performance. However, as new technologies are deployed, new reliability issues must be addressed and resolved.
- Turbines are being sited in extreme hot, cold and corrosive climates that require special design and O&M attention; and now offshore applications make system reliability even more critical as access for maintenance is limited.
- It is the manufacturer's challenge to design this new technology for reliability and ease of service.

# Reliability is defined as:

The probability that a system will perform its intended function during a specified period of time under stated conditions.

Mathematically, this may be expressed as:

$$R(t) = \int_t^{\infty} f(x) dx$$

Where  $f(x)$  is the failure probability density function.

Four key elements of this definition include:

1. Reliability is a probability and reliability wind engineering is concerned with meeting the specified probability of success at a specified statistical confidence level.

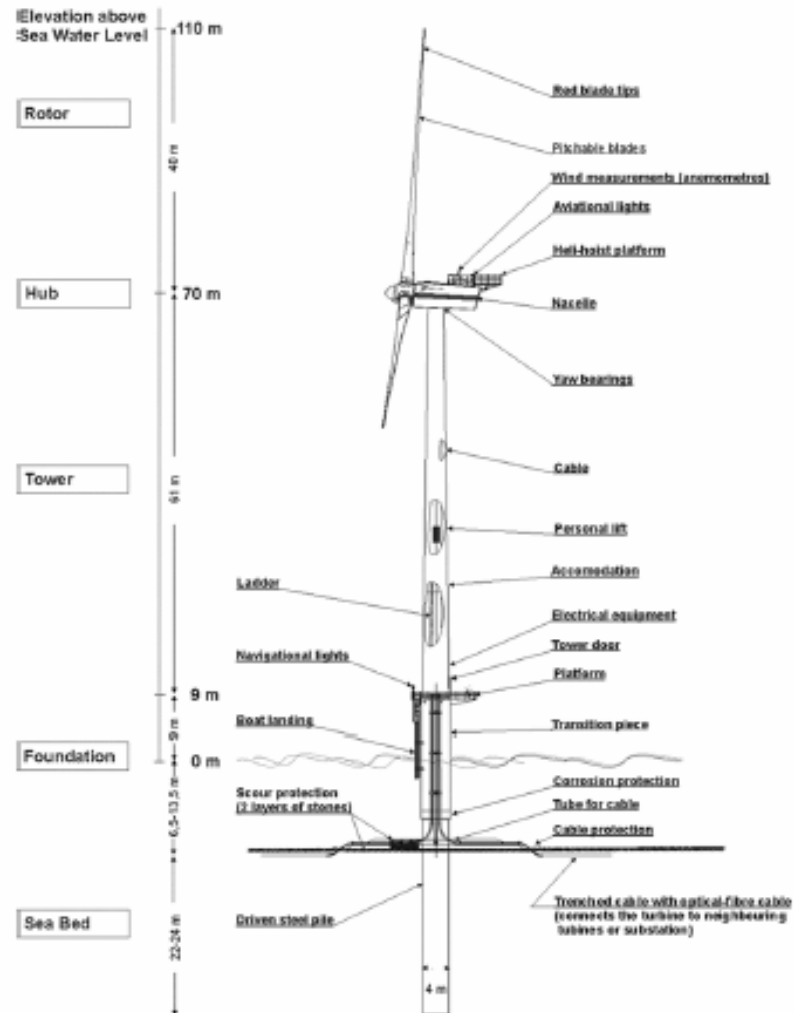
## Key elements of Reliability include (cont):

2. Reliability is predicated on "intended function:" Generally, this is taken to mean operation without failure. However, even if no individual part of the system fails, but the system as a whole does not do what was intended, then it is still charged against the system reliability. The system requirements specification is the criterion against which reliability is measured.
3. Reliability applies to a specified period of time. A wind turbine's design life, for example, is generally 20 to 30 years. In practical terms, this means that a system has a specified chance that it will operate without failure before that time. Reliability engineering ensures that components and materials will meet the requirements during the specified time. The wind industry generally specifies reliability in terms of turbine availability, power curve and acoustic output. High reliability helps assure a lower Cost of Energy.
4. Reliability is restricted to operation under stated conditions. To assure high reliability and low COE, the operating environment must be addressed during design and performance testing.

# System made up of key subassemblies...

A modern wind turbine includes the following key subassemblies:

- Rotor Blades
- Pitch Control System
- Air brake
- Mechanical brake
- Main shaft
- Gearbox
- Generator
- Yaw system
- Electrical controls
- Hydraulics
- Grid or electrical system
- Other...



Source: Vestas

# Failure intensity function: $\lambda(t)$

P.J. Tavner et al, Durham University, UK (2006) in their modeling of wind turbine reliability have shown that the [Power Law Process \(PLP\)](#) and [Homogeneous Poisson Process \(HPP\)](#) can be used to analyze the reliability of complex repairable equipment like a wind turbine.

The intensity function  $\lambda(t)$  describes the failure rate of a piece of machinery, such as a wind turbine, and has the form:

$$\lambda(t) = \frac{\beta}{\theta} \left( \frac{t}{\theta} \right)^{\beta-1}$$

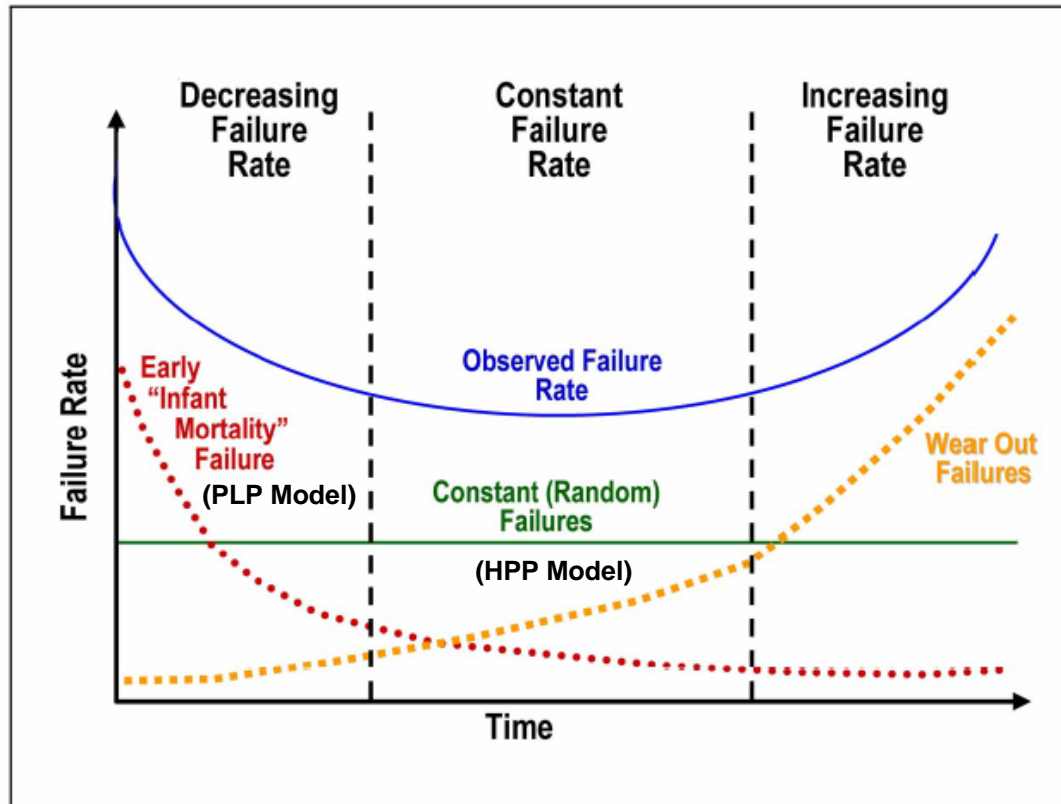
where the shape of the failure intensity curve resembles a bathtub curve with three regions :

- early failures,  $\beta < 1$ ;
- constant failure rate,  $\beta = 1$ ;
- deterioration,  $\beta > 1$ .

and  $\theta$  is the Mean Time between Failures (MTBFs) of the turbine.

Source: P.J. Tavner, J. Xiang, F. Spinato, *Reliability Analysis for Wind Turbines*, Durham University, UK, 2006

# The Bathtub curve failure function...



Source: Wikipedia, 2006: [http://en.wikipedia.org/wiki/Bathtub\\_curve](http://en.wikipedia.org/wiki/Bathtub_curve)



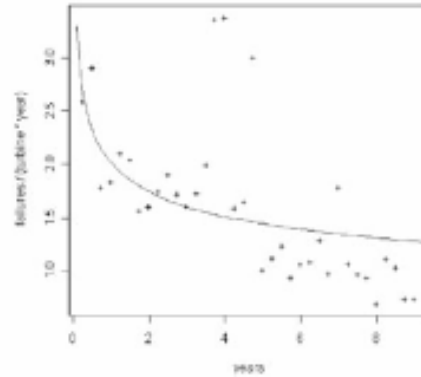
# Historical data sets evaluated...

- Reliability Analysis for Wind Turbines, P.J. Tavner et al, Durham University, UK (2005)
- Investigated 10 years of data from October 1994 to September 2004
- German survey population included up to 4,500 turbines, Danish survey included up to 2,500 turbines.
- Variations in turbine size from 100 kW to 2.5 MW
- Survey population also included variations:
  - in the drive train mechanical architecture, including direct drive from the wind rotor to a low-speed generator and indirect drive with a gearbox and high-speed generator;
  - in mechanical control for yaw;
  - and in mechanical control for speed, ranging from simple stall control, constant-speed turbines with induction generators to variable speed turbines with doubly fed induction or direct drive synchronous generators and blade pitch control.

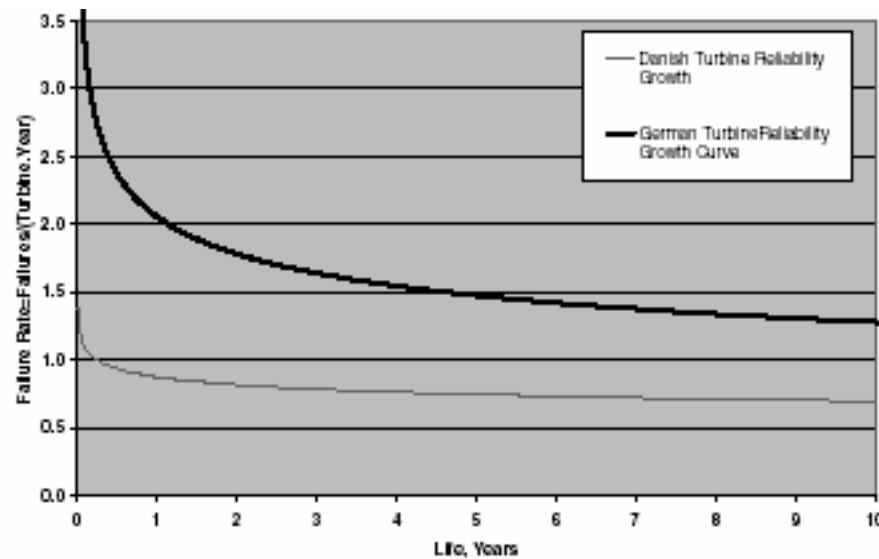
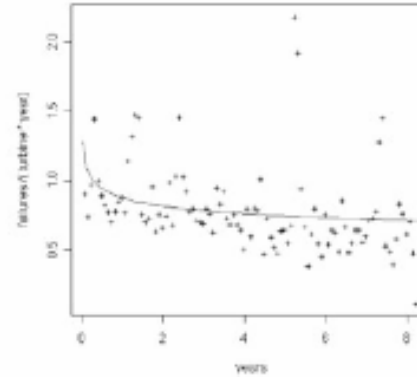
Source: P.J. Tavner, Durham University, UK, 2006

# Durham University Study Results:

German Turbine  
Reliability



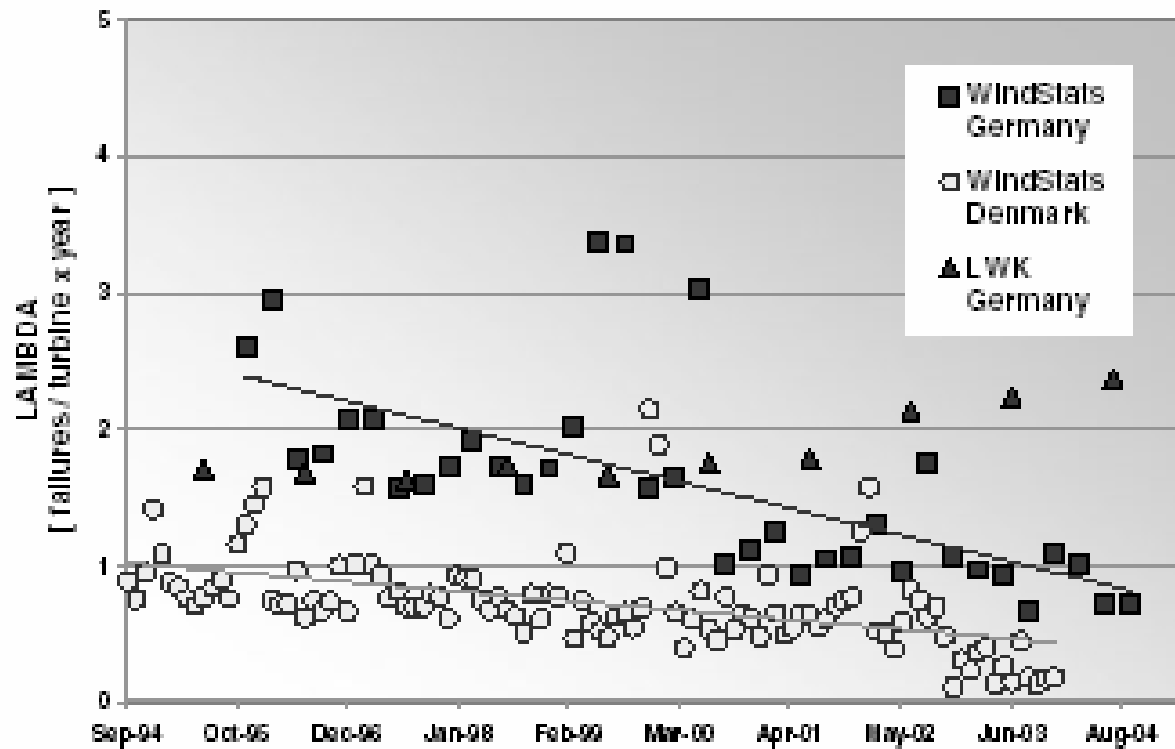
Danish Turbine  
Reliability



Reliability growth curves developed using the Power Law Process Model

Source: P.J. Tavner, Durham University, UK, 2006

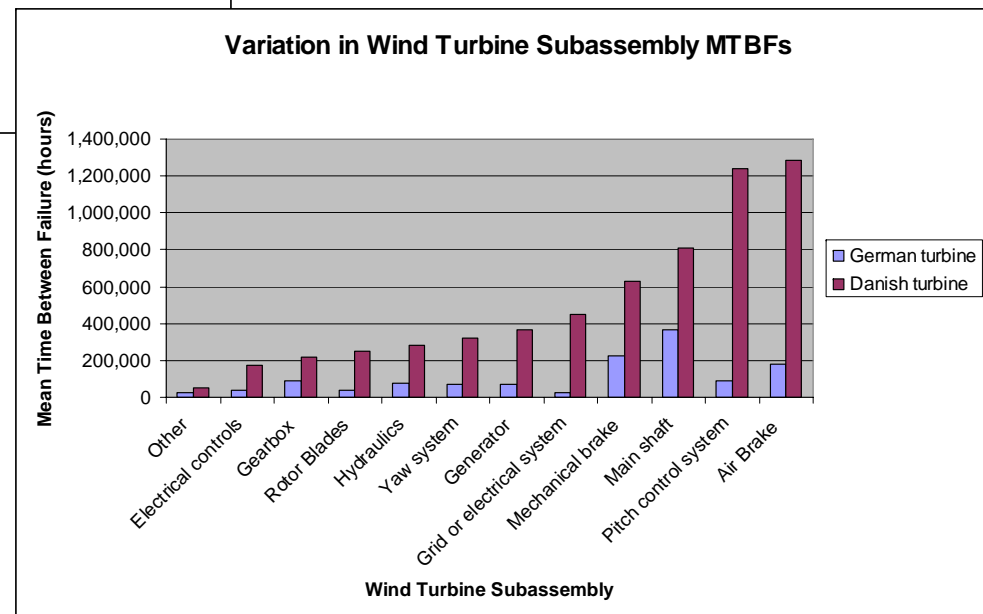
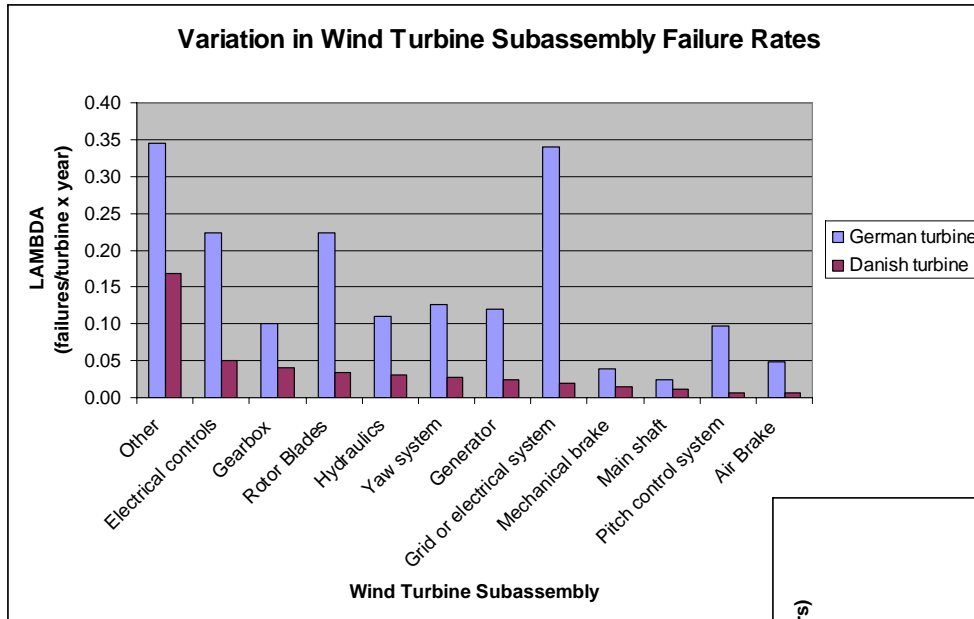
# Durham University Study Results (cont):



Failure rates using the Homogeneous Poisson Process Model (HPP)

Source: P.J. Tavner, Durham University, UK, 2006

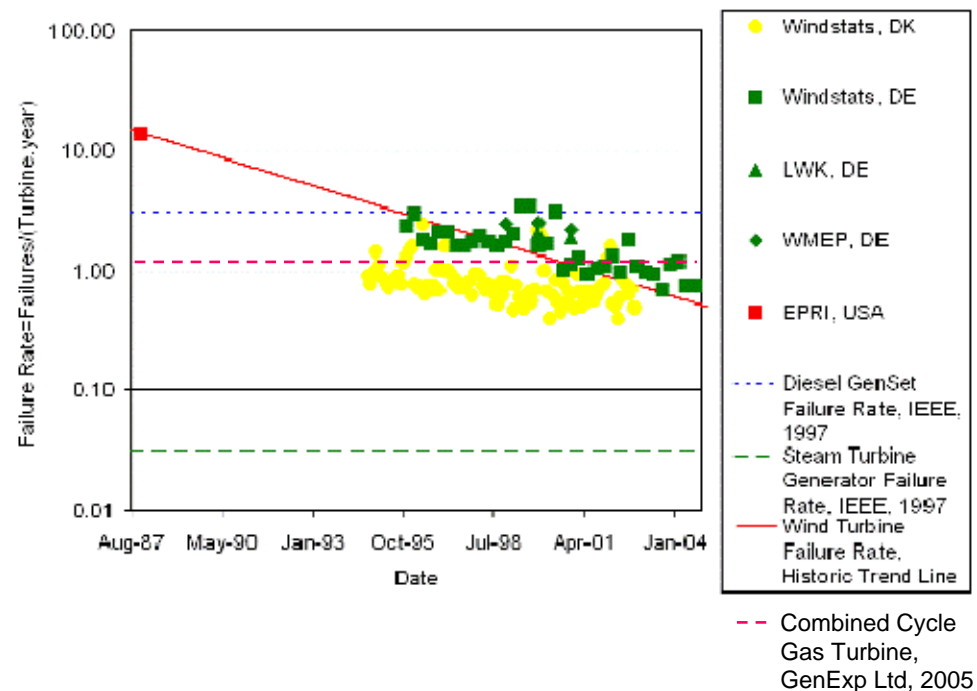
# Variation in subassembly failure rate...



Source: P.J. Tavner, Durham University, UK, 2006

# Comparison to other power sources...

This work is currently reported in [Windstats](#) Vol. 18, No. 1 - Winter 2005.

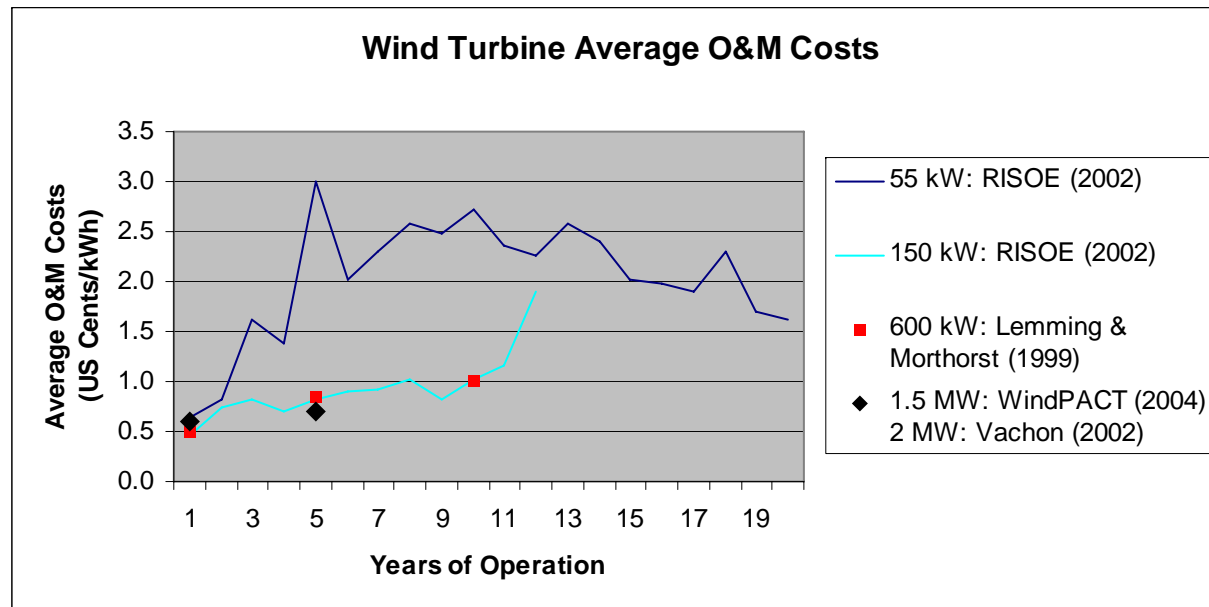


Source: P.J. Tavner et al, Durham University, UK, [www.dur.ac.uk/engineering/nareg/research/reliability/](http://www.dur.ac.uk/engineering/nareg/research/reliability/)

# Operation and Maintenance Activities...

- **Operation and Condition Monitoring**
- **Planned Maintenance** – can be anywhere from 50 to 100 hours per year per turbines. Includes oil filter changes, generator brush replacement, etc.
- **Unplanned Maintenance** - Wear out mechanism dominates on high cost items => Periodic overhauls (every 5 years) to reduce/manage unplanned maintenance costs.
- **System Overhaul** – often includes generator bearings, gearbox bearings and oil change, bearings in yaw drive and pitch drive gear boxes and usually requires a major lift crane that can account for 10 – 15% of the overhaul cost. Complete turbine overhaul can be 20% of a new turbine cost.

# Effect of turbine reliability on O&M Costs...



## Wind System Reliability

Advances in turbines and system design, coupled with a better understanding of wind gust forces, has led to a dramatic improvement in the reliability of wind energy. This has led to increased percentage ratings of *availability* for wind turbines -- a commonly used operational measure of reliability. Modern wind farms now routinely achieve availability values of 98 percent or more. Maintenance costs for wind energy systems also have improved dramatically, dropping to less than 1 cent per kilowatt-hour (kWh).

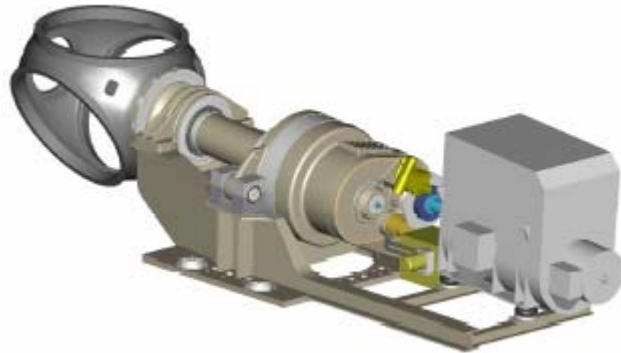
**Source: National Wind Coordinating Committee, January 1997, No. 10, Wind Performance Characteristics**

## Reliability expected and warranted...

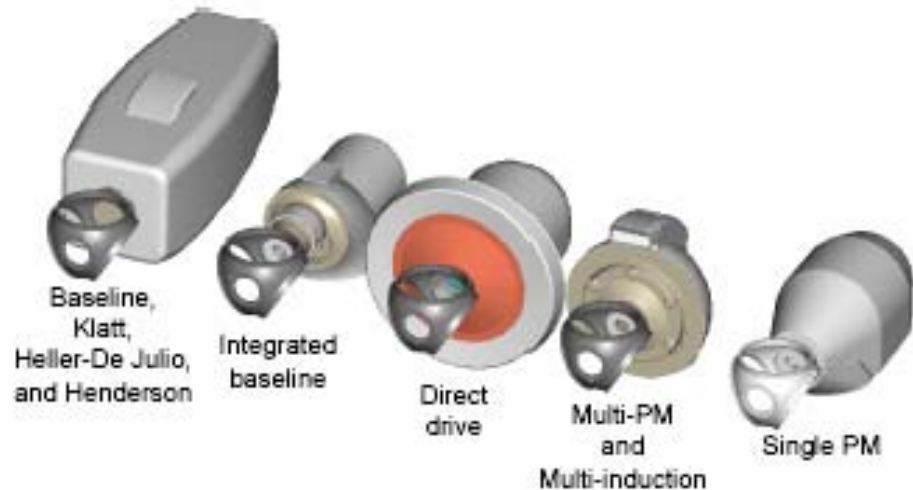
- Investors in wind projects view reliability with respect to a positive return on their investment given 20+ years operating life at their specific site.
- Turbine manufacturers guarantee turbine availability (95-98%), power curve (100%) and acoustic output (X dBA) during the warranty period (usually 2 to 10+ years).
- Turbine preventative and predictive maintenance critical in assuring high reliability.



# Reliability and COE dependent on architecture...



Baseline



WindPACT Drive Train Designs

WindPACT Advanced Wind Turbine Drive Train Designs Study, Global Energy Concepts, August 2003 concluded Single PM COE lowest at 87% of the Baseline.

Source: R. Poore and T. Lettenmaier, Alternative Design Study Report: WindPACT Advanced Wind Turbine Drive Train Designs Study, August 2003, NREL/SR-500-33196

# Improving system reliability through design...

- Define/measure relevant ambient condition X's.
  - For example: wind speed, turbulence, temperature, humidity, lightning, salinity, etc.
- Identify critical components, evaluate their performance at specification limits and understand their failure modes.
- Determine X's effect on equipment failure mode Y's via testing and analysis.
- Design control strategies to minimize ambient effects and build in redundancy for critical systems.
- Specify design requirements and component specifications to meet requirements including ease-of-service and modularity.
- Execute redesign/retrofit of components that negatively impact turbine reliability and availability.

# Improving system reliability thru O&M...

- Identify critical components that are negatively impacting Cost of Energy (COE) and develop logistics plan to address;
- Review fault events leading up to a failure and develop diagnostic tools to anticipate similar faults in other turbines;
- Maintain spare parts for critical components;
- Secure equipment and tools to support O&M activities including cranes;
- Focus on O&M documentation, training and trouble-shooting guides;
- Develop procedures for up-tower repairs;
- Implement condition monitoring; both on- and off-line with Remote Monitoring and Diagnostics through SCADA system;
- Scheduled work in sweeps during the off-season to spread crane costs over the fleet.

# Better tools to manage failures...

- Onboard cranes
- Service lifts and climbing assists



If the user weighs say 100 kg and chooses a pull of 40 kg, he only has to lift 60 kg of his own body weight. Thereby, especially injuries on knees, arms and feet are avoided.

Source: Avanti Service Lifts

## Better tools to manage failures (cont.)...

- Condition Monitoring
  - Blades: strain, temperature, lightning detection, crack detection;
  - Gearboxes: Vibration, temperature, fluid level, and oil cleanliness monitoring;
  - Generators: Temperature, voltage, current, phase imbalance;
  - Electrical: Line phase imbalance, voltage and current levels;
  - Bearings: Vibration
  - More cost effective as turbine size increases.

# Conclusions...

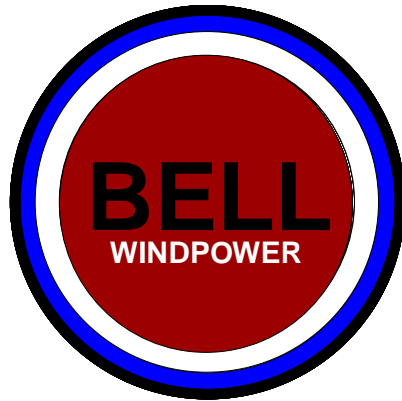
- Analysis of historical reliability data from Tavner et al and others shows there is a downward trend in wind turbine failure rates;
- Tavner et al have demonstrated the HPP model for turbine life applies to Danish turbines because their longer average age and the current failure rates lie in the constant failure region of the bathtub curve;
- Tavner has also shown that the newer German turbines require the use of the PLP model because the designs have a lower average age and the majority of the failures occur in the early failure range of the bathtub curve;
- The calculated reliability curves for the Danish and German turbines are significantly different, implying that the technologies involved are at different stages of maturity. While the failure rates in the newer German designs are higher, there is room for further improvement and trends show that these improvements are being realized;

## Conclusions (cont)...

- As turbines get larger, the costs to add more condition monitoring systems and service features like onboard cranes and personnel lifts can be justified by lower COE;
- Tavner also showed that the introduction of larger turbines in Germany with greater technological complexity, like power electronics, is raising their average failure rates in the first few years of operation, however, the downward trend in failure rates is noted to be greater than in the Danish population. This trend suggests that even though more complex, the German machines are not potentially less reliable than their simpler and smaller Danish predecessors.
- There appears to be periodicity in the failure rates of the two turbine populations, suggesting that weather events may have impacted fleet-wide failure rates.
- Reliability data for the Danish and German fleet suggest a level of reliability better than modern diesel gen-sets and trends in reliability suggest that within the next ten years, wind turbine reliability will approach that of the most reliable of thermal turbine generating sources: steam turbines.

# Thank you!

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